NPS-AM-11-C8P15R03-057

EXCERPT FROM THE PROCEEDINGS

OF THE

EIGHTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation

Eva Regnier and Dan Nussbaum, NPS

Published: 30 April 2011

Prepared for the Naval Postgraduate School, Monterey, California 93943

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
APR 2011		**00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE
The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School,Monterey,CA,93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the Naval Postgraduate School?s 8th Annual Acquisition Research Symposium, 10-12 May 2011, Seaside, CA.

14. ABSTRACT
Acquisition decisions drive resource requirements that are spread widely across the Department of Defense (DoD). DoD policy and Federal statute call for using the Fully Burdened Cost of Fuel (FBCF) in cost estimates in Analyses of Alternatives (AoAs) that support acquisition decision making so that decisions reflect all of the costs throughout the DoD organization that will be incurred (or saved) by a given acquisition decision. An Economic Input/Output (EIO) model of the DoD organization could be used to estimate the unit-specific FBCF, capturing all higher-order effects as demand is propagated through a complex and nonlinear supply chain. The model would produce unit-specific estimates of the cost and DoD-wide fuel requirements associated with a marginal change in fuel requirements in any unit of the organization. This paper describes the feasibility and potential benefits of an EIO model of DoD fuel supply.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**16**	

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request Defense Acquisition Research or to become a research sponsor, please contact:

NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret.)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.acquisitionresearch.net

Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
- Program Executive Officer SHIPS
- Commander, Naval Sea Systems Command
- Army Contracting Command, U.S. Army Materiel Command
- Program Manager, Airborne, Maritime and Fixed Station Joint Tactical Radio System

- Program Executive Officer Integrated Warfare Systems
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
- Deputy Assistant Secretary of the Navy (Acquisition & Logistics Management)
- Director, Strategic Systems Programs Office
- Deputy Director, Acquisition Career Management, US Army
- Defense Business Systems Acquisition Executive, Business Transformation Agency
- Office of Procurement and Assistance Management Headquarters, Department of Energy

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this Symposium.

James B. Greene, Jr.	Keith F. Snider, PhD
Rear Admiral, U.S. Navy (Ret.)	Associate Professor

Panel 15 – Analysis for Enhanced Acquisition Decision-Making

Thursday, May 12, 2011	
9:30 a.m. – 11:00 a.m.	**Chair: J. David Patterson,** Executive Director, National Defense Business Institute, The University of Tennessee ***The Effect of Processes and Incentives on Acquisition Cost Growth*** Doug Bodner, Bill Rouse, and I-Hsiang Lee, Georgia Institute of Technology ***The Failures and Promises of an Operational Service-Oriented Architecture: The ROI of Operational Effectiveness in Addition to Acquisition Efficiency at the Navy's Op Level of War*** Richard Suttie, U.S. Naval War College, and Nicholas Potter ***The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation*** Eva Regnier and Dan Nussbaum, NPS

David Patterson—Executive Director, National Defense Business Institute, University of Tennessee. Mr. Patterson is establishing an institution inspiring business innovation for both government and industry at the University of Tennessee in the College of Business Administration by providing practical, sound assistance in creating economically efficient and effective Defense business and acquisition programs. He is responsible for preparing funding proposals and budgets and for recruiting and managing university staff, professors, other faculty members, and key subject-matter experts engaged in relevant research and resource development tasks.

Prior to his current duties, he was the Principal Deputy Under Secretary of Defense (Comptroller). As the Principal Deputy, he was directly responsible for advising and assisting the Under Secretary of Defense (Comptroller) with development, execution, and oversight of the DoD budget, exceeding $515 billion, with annual supplemental requests of more than $160 billion. He was also responsible for developing legislative strategies and developing and implementing DoD financial policy, financial management systems, and business modernization programs. In June 2005 Mr. Patterson was appointed to lead the Defense Acquisition Performance Assessment Project, a comprehensive evaluation of every aspect of the Defense Department acquisition system and decision making processes.

From August 2003 to June 2005, Mr. Patterson held duties as The Special Assistant to the Deputy Secretary of Defense. In the capacity as Special Assistant, Mr. Patterson was responsible for managing the Deputy Secretary of Defense's personal staff as well as providing direction and advice to the Office of the Secretary of Defense Staff on a wide range of national security operations and policy subjects. He contributed to the Department of Defense support to the United States' mission to establish free and economically successful societies and governments in Iraq and Afghanistan. Additionally, Mr. Patterson supported the Deputy Secretary in the areas of military commissions for detainees in the Global War on Terrorism and major defense acquisition programs.

Before returning to government service, Mr. Patterson was a founding and managing partner at Bucher, Hutchins, Kohler and Patterson, Inc., where he led the firm's commercial consulting practice, developing management strategies for acquiring new business. From 1999 to 2001, he was the Vice

President and Site Manager for Steven Myers and Associates' support to Lockheed Martin Corporation's winning Joint Strike Fighter competitive proposal preparation.

Between 1993 and 1999, Mr. Patterson held a variety of responsible, executive positions at McDonnell Douglas Corporation (later The Boeing Company), beginning as the Senior Manager for Market Research and Analysis on the C-17 military air cargo aircraft and later as Director, International Business Development. He was responsible for developing and executing the business capture strategy that won U.S. Government Defense Acquisition Board approval to procure 80 additional C-17s, completing the first contract for 120 aircraft. Mr. Patterson led the Boeing business development team that launched the initiative to introduce a commercial version of the C-17; the BC-17.

Mr. Patterson served in the Air Force from 1970 to 1993, retiring in the rank of colonel. During that time, he held responsible leadership and management positions, with assignments at the air wing level as a C-5A aircraft commander and Deputy Operations Group Commander, at major command headquarters, Headquarters, U.S. Air Force, the Office of the Chairman, Joint Chiefs of Staff and the Office of the Secretary of Defense, Inspector General. In 1986, Mr. Patterson was the Air Force Fellow at the American Enterprise Institute. He served in Vietnam flying O2As as forward air controller.

The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation

Eva Regnier—Associate Professor of Decision Science, Defense Resources Management Institute (DRMI), and Visiting Associate Professor, Operations Research Department, NPS. She received a PhD in Industrial Engineering and an MS in Operations Research from the Georgia Institute of Technology, and a BS in Environmental Engineering Science from the Massachusetts Institute of Technology. Dr. Regnier teaches decision analysis and management of defense resources. Her research is in decisions under uncertainty, including both optimization and characterizing uncertainty for decision-makers, with a focus on applications with sources of uncertainty in the natural environment. [eregnier@nps.edu]

Dan Nussbaum—Professor, Operations Research Department, NPS. Dr. Nussbaum teaches cost estimating, does research, and mentors students. He has been a Principal with Booz Allen Hamilton, Director, Naval Center for Cost Analysis, and has held other management and analysis positions with the U.S. Army and Navy in the U.S. and in Europe. He has a BA in Mathematics and Economics from Columbia University and a PhD in Mathematics from Michigan State University. He has held postdoctoral positions in Econometrics and Operations Research and in National Security Studies at Washington State University and Harvard University. [danussba@nps.edu]

Abstract

Acquisition decisions drive resource requirements that are spread widely across the Department of Defense (DoD). DoD policy and Federal statute call for using the Fully Burdened Cost of Fuel (FBCF) in cost estimates in Analyses of Alternatives (AoAs) that support acquisition decision making so that decisions reflect all of the costs throughout the DoD organization that will be incurred (or saved) by a given acquisition decision. An Economic Input/Output (EIO) model of the DoD organization could be used to estimate the unit-specific FBCF, capturing all higher-order effects as demand is propagated through a complex and nonlinear supply chain. The model would produce unit-specific estimates of the cost and DoD-wide fuel requirements associated with a marginal change in fuel requirements in any unit of the organization. This paper describes the feasibility and potential benefits of an EIO model of DoD fuel supply.

Introduction

Acquisition decisions drive resource requirements that are spread widely across Department of Defense (DoD) organizational components. These decisions include Analyses of Alternatives (AoA) and Milestone decisions supported by Life Cycle Cost Estimates (LCCE). An important component of LCCE is energy usage (primarily fuel) during the Operating and Support phase. To provide more realistic cost estimates of fuel, the DoD has mandated use of “fully burdened cost of fuel” (FBCF). The purpose of this research effort is to evaluate the feasibility of developing an Economic Input/Output (EIO) model of the DoD organization to estimate the FBCF and thereby to support acquisition decisions.

DoD fuel usage creates risk by tethering deployed forces to a long and costly supply chain and by making the DoD strategically dependent on foreign oil sources. DoD policy and Federal statute call for using the Fully Burdened Cost of Fuel (FBCF) in cost estimates in Analyses of Alternatives (AoAs) that support acquisition decisions so that these decisions reflect all of the costs throughout the DoD organization that will be incurred (or saved) by a given acquisition decision. One of the challenges in estimating the FBCF is that a reduction

(increase) in fuel requirement in one part of the organization has a cascading effect because it reduces (increases) demands on supporting organizations, multiplying the effect of a change in usage along the transportation supply chain getting the fuel to its point of use. Current FBCF models do not capture this multiplier effect, with the result that the true cost of fuel is underestimated.

Economic Input/Output (EIO) earned the Nobel Prize in economics for its creator, W. Leontief (Leontief, 1986), but it is a fairly simple model. Usually applied to a national economy, using industries and sub-industries as the unit of analysis, EIO produces a general equilibrium model, so that the impact of marginal changes in one sector can be propagated and measured through the rest of the economy. The research literature is rich with applications to Life Cycle Assessment, which is the estimation of the environmental impacts of the consumption of products and services traced back through a complex supply chain (Hendrickson, Lave, & Matthews, 2006). An EIO system for the DoD would have organizational units as sectors (which we call components), and marginal changes in output or input requirements in one component could be propagated through the entire system to estimate the net effects on the entire organization.

The primary benefits of EIO are its ability to capture all higher-order effects of a change in one part of the organization and the ability to trace resource-specific requirements throughout the system. For example, an EIO system could estimate not only the total costs of FBCF (specific to every organizational unit) but also the total DoD-wide reduction in fuel demand associated with a reduction of one gallon of fuel in a given unit. The EIO method can be used to capture the costs of force protection.

In the context of FBCF, an EIO system could be used to develop a more credible value for FBCF by producing an estimate of the DoD-wide effect of reducing (or increasing) fuel or power demand. The estimated FBCF would be specific to an organizational unit, as appropriate because the requirements involved in providing a gallon of fuel differ across organizational units, depending in particular on the supply chain that sustains the unit.

The section FBCF Using Unit Costs vs. EIO Estimate uses a simple example to show how the EIO approach can be adapted to model the DoD fuel supply chain and illustrate the multiplier effect. The Modeling the Supply Chain with EIO section provides a formal EIO model for DoD fuel supply and shows examples of the calculations. The section Feasibility Considerations discusses feasibility and challenges of the approach, and the final section concludes with a discussion of the potential advantages and disadvantages of EIO relative to scenario-based approaches to estimating the FBCF.

FBCF Using Unit Costs vs. EIO Estimate

Consider a very simple model of a supply chain that provides fuel to a single warfighting unit. We will call the warfighting unit a “component,” where a component is the organizational subunit that is directly modeled, equivalent to an industry or sector in classical EIO. The supply chain includes three logistical stages, each of which is a component as well as the end user component that uses the fuel in warfighting.

Fuel delivered is the total number of units (here, gallons) of fuel that each stage delivers to its customers. In this example, the supply chain is linear, so each stage has exactly one supplier (the prior stage, or, in the case of Stage 1, an external purchase) and exactly one customer (the next stage, or, in the case of Stage 3, the warfighting component).

Fuel operating costs exclude the cost of the delivered fuel. It includes the cost of the fuel consumed by this component in providing its services calculated at the official Defense Energy Support Center (DESC) standard price, which in this example is $2/gallon. The other (non-fuel) costs include operating and support (O&S) costs, depreciation, infrastructure and recapitalization, and infrastructure—everything attributable to the logistical component and capturing cost elements 2-5 in the FBCF methodology (Fully Burdened Cost of Fuel Calculator, version 7, Model Description & Assumptions, March 2010).[1]

The naive application of the FBCF calculation for the logistical support would attribute the unit cost of delivered fuel by each supply-chain component to a unit of fuel provided to the consuming component. Table 1 shows an example calculation; the FBCF estimated cost of the supply chain per gallon of fuel delivered to the warfighter component is $4.45, the sum of the unit operating costs of the three supply-chain components. Adding the $2/gallon DESC price, this comes to an estimate of $6.45 for the FBCF. This would be appropriate in a one-stage linear supply chain. However, it doesn't work in a multistage supply chain.

Table 1. Example Calculation of Delivery Cost in Three-Stage Supply Chain

	Fuel Delivered (gal)	Fuel Consumption (% of delivered)	Operating Costs: Non-Fuel	Operating Costs: Fuel	Operating Costs: Total	Operating Costs/Unit Delivered
Stage 1	1560	15%	$ 1,532	$ 468	$ 2,000	$ 1.28
Stage 2	1200	30%	$ 1,280	$ 720	$ 2,000	$ 1.67
Stage 3	1000	20%	$ 1,100	$ 400	$ 1,500	$ 1.50
			$ 3,912	$ 1,588	$ 5,500	$ 4.45

Figure 1 shows the multiplier effect on the total quantity of fuel required at each stage (note that it does not show costs). Because Stage 3 requires 0.2 extra gallons of fuel for every gallon it delivers, then to deliver 1,000 gallons of fuel, it must receive 1,200 gallons from Stage 2. If the fuel demand from the warfighter were reduced by a gallon, then Stage 3 would have to receive 1.2 gallons less, not just 1 gallon less.

[1] The seven cost elements are:

1. Commodity Cost of Fuel.
2. Primary Fuel Delivery Asset O&S Cost.
3. Depreciation Cost of Primary Fuel Delivery Assets.
4. Direct Fuel Infrastructure O&S and Recapitalization Cost.
5. Indirect Fuel Infrastructure O&S Cost.
6. Environmental Cost.
7. Other Service & Platform Delivery Specific Costs (including force protection).

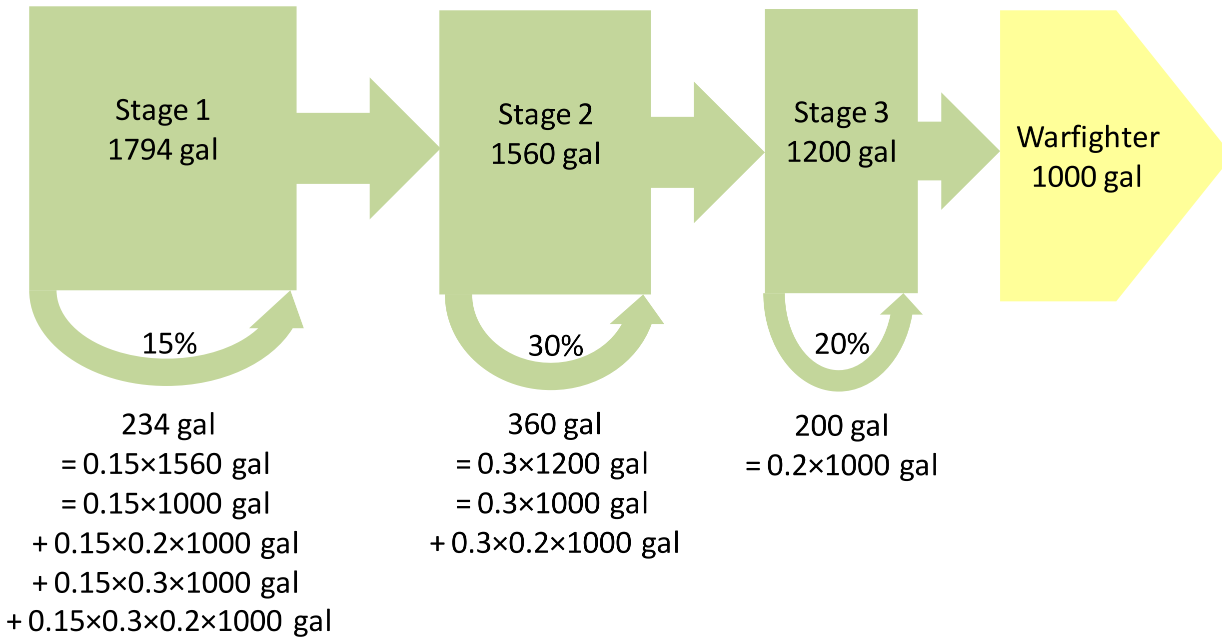

Figure 1. Multiplier Effect in Simple Supply Chain

In the example in Table 1, the appropriate fully burdened cost of a gallon of fuel (hereafter the EIOCF) is the total cost of operating all three supply-chain components including the costs of the extra fuel required by each supply-chain component to deliver the 1,000 gallons of fuel needed by the warfighter plus the fuel required to deliver the extra fuel required by the downstream components as detailed below:

$2000 = 1000 gal ×$2/gal for fuel used by the warfighter component
$300 = 0.15×1000 gal ×$2/gal for extra fuel used in Stage 1 to transport 1000 gal
$600 = 0.3×1000 gal ×$2/gal for extra fuel used in Stage 2 to transport 1000 gal
$90 = 0.15×300 ×$2/gal
= for extra fuel used in Stage 1 to transport extra 300 gal to Stage 2
$400 = 0.2×1000 gal ×$2/gal for extra fuel used in Stage 3 to transport 1000 gal
$120 = 0.3×200 ×$2/gal
= Stage 2 cost to transport the extra 200 gal needed at Stage 3
$60 = 0.15×200 ×$2/gal
=Stage 1 cost to transport the extra 200 gal needed at Stage 3
$18 = 0.15×60 ×$2/gal
= Stage 1 cost to transport the extra 60 gal required at Stage 2 to transport the extra 200 gal needed at Stage 3

$3,588= Total Fuel Cost, including $2,000 for fuel used by warfighter component and $1,588 for fuel used by supply chain

The total direct fuel cost to transport 1,000 gallons: $1,300 = 1,000 gallons × (0.15 + 0.2 + 0.3) × $2/gallon. This is the only fuel cost that would be captured by a naive FBCF estimate. In this example, the total non-fuel cost of the supply chain is $3,912, so the total cost of supply chain plus direct cost of 1,000 gallons of fuel is $7,500, and the total cost of the supply chain per unit of fuel consumed by the warfighter is $7.50, which we will call the EIO cost of fuel (EIOCF).

EIOCF = $7.50/gallon.

The EIOCF of $7.50/gallon contrasts with the FBCF of $6.45 calculated above if the multiplier effects are not captured. In this simple example, that is a difference of $1.05/gallon, which is 16% of the total cost of the delivered fuel (including non-fuel costs to the supply chain) and 29% of the fuel costs of the delivered fuel.

If we assume that, like fuel costs, the non-fuel costs of the supply chain components are proportional to the quantity of fuel that each component delivers, then the EIOCF is the marginal cost of a gallon of fuel delivered to the warfighter. In the example in Table 1, increasing the quantity demanded by the warfighter to 1,001 gallons would increase the total cost of the supply chain to $7,507.50. Therefore, the EIOCF is the appropriate cost to use in decisions—acquisition decisions, operational decisions, even force planning decisions—that can affect warfighter fuel requirements. The naive FBCF underestimates the marginal cost of a gallon of fuel consumption.

While it is certainly possible for an analyst to estimate the multiplier effects when conducting a FBCF analysis, it would be difficult as it requires estimating the amount of fuel that a unit transports that is destined for the end user rather than other elements of the supply chain, and in general at most second-order effects are captured.

Modeling the Supply Chain with EIO

Modeling a system using EIO requires first, defining the components or unit of analysis, which determines the level of data that will be required to populate the model. Second, the model requires a populated matrix of the type shown in Table 2. An EIO model is a static snapshot representing the flows of resources among components of the modeled system. For national accounts, the snapshot is usually an annual total. For the DoD, an annual average or total representation of the supply chain would likely be used and results would reflect averages over the period. This section formalizes the model.

Linear Supply Chain

Components are indexed $i = 1,\ldots,n$, where n is the warfighter component, and $1,\ldots, n-1$ are links in the supply chain transporting fuel to component n. Think of component $i=1$ as DESC (DLAE), and each component $i<n$ directly supplies only component $i+1$. Each supply component has precisely one output: delivered fuel. The amount of fuel delivered by each component is denoted x_i.

Using the convention of EIO analysis, let a_{ij} = the number of units of output from component i required to produce each unit of output from component j. Often, both a_{ij} and x_i are normalized in terms of dollars. We will instead assume a_{ij} and x_i are in units of fuel, with all fuel treated identically. The exception is x_n, the output of the warfighter component, which might be steaming hours, patrols performed, or other output measures.

We will also introduce an external component, indexed X, which represents any supplier outside the organization. In our example, this captures purchases of fuel from the private sector. In classical EIO, the entire economy is modeled. In some cases, such as national accounting, imports are purchases external to the organization.

The total fuel requirement for the organization is $\sum_{j=1}^{n} x_j a_{Xj}$. The input-coefficient matrix is shown in Table 2.

Table 2. General Input-Coefficient Matrix

			destination			
			component			
			1	2	3	n
source	component	1	a_{11}	a_{11}	…	a_{1n}
		2	a_{21}	a_{22}	…	a_{2n}
		…	…	…	…	…
		n	a_{n1}	a_{n2}	…	a_{nn}
		external	a_{X1}	a_{X2}	…	a_{Xn}

The values of a_{ij} and x_i satisfy the n equalities:

$$x_i = \sum_{j=1}^{n} a_{ij} x_j, \forall i = 1, \ldots, n,$$

which means that each component i produces exactly enough of its output, x_i, to satisfy the input demands of all components for its output. The above can be rearranged as follows:

$$x_i = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{n} a_{ij} x_j}{1 - a_{ii}}. \tag{1}$$

Since we are assuming a very simple supply chain in which component 1 supplies component 2 (and no one else) and so on, and the model accounts for exactly one input type (fuel), the input coefficient matrix has a special structure:

$$\forall i = 2, \ldots, n-1 \; a_{i-1,i} = 1 + \alpha_i \text{, and } a_{ij} = 0, \; \forall j \neq i+1,$$[2]

where the value α_i is the amount of fuel consumed by component i in delivering one unit of fuel. It is assumed that the fuel any component consumes is not its own delivered (output) fuel, but rather the fuel delivered by the component that supplies it.[3] The input-coefficient matrix is given in Table 3.

[2] We will further assume that the units of output from component n are defined in such a way that $a_{n-1,n} = 1$, although this is for simplicity and is not otherwise required because the output from component n is of a different type than components $i < n$.

[3] A fuel-supplying component's efficiency is therefore $1/(1+\alpha_i)$.

Table 3. Coefficient Matrix for Linear Supply Chain

			Destination				
			Component				
			1	2	…	$n-1$	n
Source	component	1	0	$1+\alpha_2$	…	0	0
		2	0	0	…	0	0
		…	…	…	…	…	…
		$n-2$	0	0	…	$1+\alpha_{n-1}$	0
		$n-1$	0	0	…	0	$a_{n-1,n}$
		n	0	0	…	0	0
		External	$a_{X1}=1+\alpha_1$	0	…	0	0

For components $i<n$, each component's output (gallons of fuel) is: $x_i = a_{i,i+1}x_{i+1} = \left(1+\alpha_{i+1}\right)x_{i+1}$, and the total organizational fuel requirement is

$$x_X = \prod_{i=1}^{n-1}\left(1+\alpha_i\right)a_{n-1,n}x_n \tag{2}$$

$x_X = x_1 a_{X1} = \prod_{i=1}^{n-1}\left(1+\alpha_i\right)a_{n-1,n}x_n$, as shown in the example below, with three supply chain links (components 1-3) and one warfighter component (4). The warfighter component's output is exogenous, and it is arbitrarily set to 100. The total fuel required by the organization is 1.15 × 1.3 × 1.2 × 1,000 = 1,794.

Table 4. Input Coefficient Matrix for Simple Supply Chain Example

input coefficient matrix

	destination	component			
	source	1	2	3	4
component	1	0	1.3	0	0
	2	0	0	1.2	0
	3	0	0	0	1
	4	0	0	0	0
	external	1.15	0	0	0
	output by component	1560	1200	1000	1000
	total external requirement	**1794**			

For a given component, we will define its fuel multiplier (denoted β_i) as the factor by which the organization's total fuel requirement from the external source would increase (decrease) with a change in the component's fuel output (either as a result of decreased demand from the next stage in the supply chain, or as a result of an increased efficiency) or decrease in demand for its product. The EIO approach assumes that changes in input requirements are proportional to changes in output (constant returns to scale). Hence,

$\beta_i = {x_X}/{x_i}$. We can rewrite Equation 2 as $x_X = \prod_{j=1}^{i}\left(1-\alpha_j\right)x_i$, for any $i = 1,...,n-1$ implying that $\beta_i = {x_X}/{x_i} = \prod_{j=1}^{i}\left(1-\alpha_j\right)$.

More Complex Supply Chain

Within the DoD it is more realistic for a supply chain to include complexities such as:

- multiple warfighter components;
- force protection components distinct from warfighting components, which produce an output (protection) that warfighting and logistics components may use;
- each component may receive fuel directly from more than one fuel-supply component; and
- nonlinearities (e.g., one component may both supply and be supplied by another component).

In this case, the general matrix in Table 2 is applicable, together with a vector of outputs, x_i for all i. The consistency constraints in Equation 1 still apply. An example is shown in Figure 2.

As before, a_{ij} = the number of units of output from component i required to produce each unit of output from component j, and the units are the units of i's output over then units of j's output. This means that $a_{ij}x_j$ is the amount of output of component i consumed by component j in the same units that component i's output is measured. The output of force-protection components is also not in units of fuel but rather in units of force protection.

Additional constraints are required to ensure that each component receives the required amount of input of a given type. In particular, if component j supplies fuel, then the total input it receives from all fuel-supplying components must equal $1+\alpha_j$.

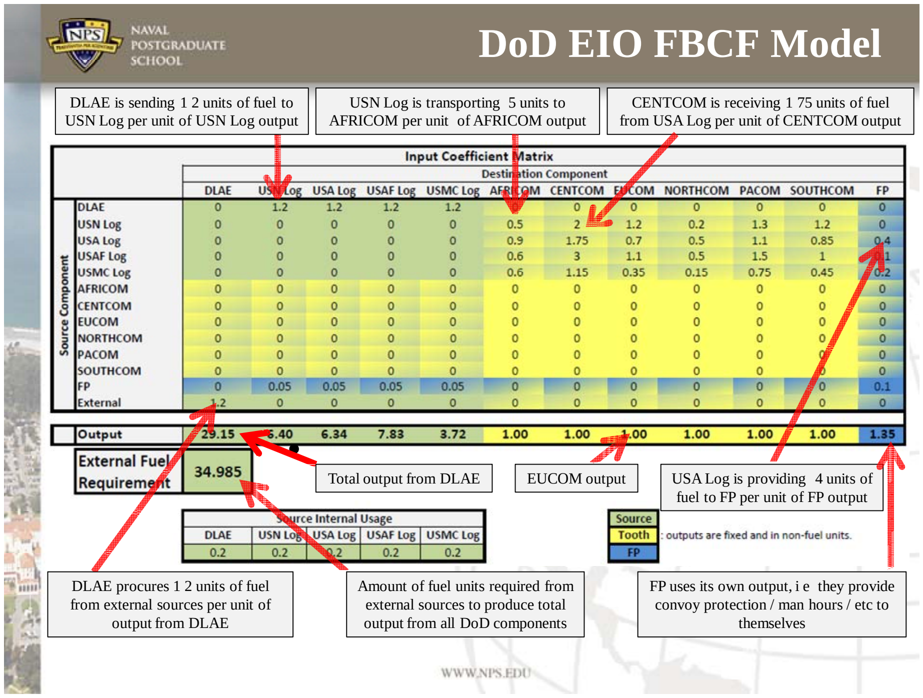

Figure 2. An Example Implementation of a DoD EIO Model that Includes Multiple Warfighter Components (the COCOMS) and Force Protection (FP)
(Dubbs & Hills, 2011)

Feasibility Considerations

The first challenge in this effort is identifying the unit of organization that can serve as the element of analysis (which we call component) for a DoD EIO Defense Accounts system. This modeling choice represents a tradeoff among data availability, data quality, and homogeneity of activities within the selected unit. The components should be defined such that the necessary coefficients can be estimated, but that the output of each component is homogenous enough that each unit of output can be treated identically.

EIO cannot be done piecemeal—it requires a fully populated matrix of the type shown in Table 2. Therefore, to calculate the EIOCF for any unit, it would be necessary to implement a DoD-wide EIO system of defense accounts. This is analogous to national accounts in the usual applications of EIO to analyze regional and sector economies (see Dietzenbacher & Lahr, 2004 for a history of the development of EIO theory and practice and for examples of EIO in national accounting), and therefore can be used in many cost estimation applications. A DoD EIO system should be DoD-wide because of the Joint nature of supply and logistics. Once such a system is implemented, it could be used to assess the impact of marginal changes within any unit in the organization. The computational effort required to estimate the impacts of additional marginal changes is negligible.

All modeling techniques have their limitations. The most relevant in this application of EIO are the following:

1. Data availability is, as always, important. We believe that the data required for this effort are available, but they do reside in several organizations across the DoD enterprise. To capture the net DoD fuel requirement associated with fuel consumption in each component, fuel flows across components within the DoD need to be estimated. In addition, to provide a dollar estimate of

EIOCF, each component's total costs associated with fuel logistics must be estimated. If force protection, a significant part of the burden of fuel supply in some operations, is to be included, then the costs associated with each component that supplies force protection to the supply chain, as well as the component's fuel requirements and suppliers and the amount of force protection output provided to each component, must be estimated.

2. EIO has assumptions—as do all models—that can limit its applicability. Principal among these for EIO is the proportionality assumption. Therefore, defining the unit of analysis (the components) such that proportionality is a reasonable assumption will be an important consideration.
3. EIO is a static snapshot of the modeled system. Especially in active operational contexts, the DoD supply chain may be changing frequently, sometimes over a matter of days or weeks. EIO allows for a given component to receive fuel (or other resources) from multiple supplying components with the resulting EIOCF estimates reflecting averages over all paths that fuel takes to reach each component. However, if the proportions of fuel change significantly, permanently, and frequently, then the static EIO matrix will be an inadequate model and provide inaccurate FBCF estimates.

The EIOCF may provide less precision for a given scenario than an approach that requires a detailed study of the particulars of the scenario. However, by definition, any detailed scenario is quickly outdated. An EIOCF might be a better estimate than an outdated detailed scenario, and may prove a better estimate of the marginal cost of fuel in a fast-changing or complex supply chain.

Conclusions

The up-front costs of populating a DoD-wide model with good data are higher than a few single-scenario FBCF studies. However, once the model is developed, it can answer questions about the marginal impacts of changes in any component with much less work per query. The EIO framework and, if implemented, a populated EIO model of the DoD supply chain could also be used to estimate the cost and resource requirements associated with any marginal change in output requirements or input mix in any unit of the organization, thus becoming a valuable tool to support many acquisition-related decisions. It is worth exploring the feasibility of constructing a EIO model of the DoD supply chain because the potential benefits for decision support are so great.

References

Dietzenbacher, E., & Lahr, M. L. (Eds.). (2004). *Wassilly Leontief and input-output economics*. Cambridge, MA: Cambridge University Press.

Dubbs, S., & Hills, J. (2011, March 30). *Economic input output analysis applied to DoD fully burdened cost of fuel*. Presentation at the Naval Postgraduate School.

Hendrickson, C. T., Lave, L. B., & Matthews, H. S. (2006). *Environmental life cycle assessment of goods and services: An input-output approach*. Resources for the Future.

Leontief, W. (1970). Environmental repercussions and economic structure—Input-output approach. *Review of Economics and Statistics*, *52*(3), 262–271.

Leontief, W. (1986). *Input-output economics* (2nd ed.). New York, NY: Oxford University Press.